7.0 AVAILABILITY

This chapter presents estimates of the availability of surface water and groundwater for future uses.

7.1 SURFACE WATER

7.1.1 Introduction

The following subsections describe the analysis of existing surface water data, creation of spreadsheet-based surface water models, and use of the models' output to estimate water availability. The modeled results described herein denote physically available water over and above existing uses, which is to be distinguished from legal or permitted availability. As projects are proposed in the future, surface water availability will be reduced due to environmental and administrative requirements; lack of physical availability of water for a project is an obvious fatal flaw for any water development. Determining physical availability is the important first step in assessing the viability of any future project.

7.1.2 Methodology

The physically available surface water was determined through the construction and use of a spreadsheet simulation model that calculated water availability based on the physical amount of water present at specific locations of water resource features such as points of diversion, reservoirs, tributary confluences and gages, compact requirements, instream flows, and minimum flows. The determination of available surface water is broken down into the following seven components:

- Compilation of historic streamflow records.
- Study period selection.
- Data extension.
- Estimating natural flow at ungaged model nodes.
- Determining streamflows during wet, normal, and dry years.
- Spreadsheet model development and calibration.
- Determination of physically present surface water.

The *Guidelines for Development of Basin Plans* published by the WWDC in 2001 recommends that for the purposes of the river basin planning process, a hydrologic analysis be conducted for three periods using average dry year conditions, average normal year conditions, and average wet year conditions. Therefore, each hydrologic region in a basinwide model has three associated spreadsheet models representing these three hydrologic conditions. The gaged flows used in the three hydrologic condition spreadsheet models are developed by averaging recorded monthly streamflows to determine groups of years falling into those three hydrologic categories during a consistent period of record. The high and low twenty percentile flow years become the wet model and the dry model, respectively, with the middle 60 percent representing the normal years. The study period has been extended since the 2001 modeling effort, for which the study period was 1971-1998, and thus the new determinations of dry, normal, and wet hydrologic conditions is slightly different.

To determine the study period, historic streamflow records were analyzed for the Green River Basin. In the selection process, major events that would have affected streamflow were considered such as the major construction or alteration of dams that would have major effects on all stream gages located below the dam. These events were minimized to the extent possible and the selected study period for the Green River Basin is 1971-2007 for this basin planning report. The period selected from 1971 through 2007 contains extended periods of dry years including some of the driest years of record as well as periods of normal and wet hydrologic conditions. The selected study period also has the greatest abundance of recorded streamflow data and ditch diversion data and therefore requires less data extrapolation.

7.1.3 Surface Water Model

The purpose of the statewide planning process is to provide decision-makers with current, defensible data to allow them to manage water resources for the benefit of all the state's citizens (Wyoming Framework Water Plan, 2007). Spreadsheet models were developed to determine average monthly streamflow in the Basin during wet, normal, and dry years. The purpose of these models was to validate existing Basin uses, assist in determining the timing and location of water physically available for future development, and help to assess impacts of future water supply alternatives. The WWDC specified that the river basin models be consistent and use software available to the average citizen. Accordingly, Microsoft® Excel was selected as the software to support the spreadsheet modeling effort.

Model Overview

For each Green River sub-basin, three models were developed reflecting each of three hydrologic conditions: dry, normal, and wet year water supply. The spreadsheets each represent one calendar year of flows, on a monthly time step. The modelers relied on historical gage data from 1971 to 2007 to identify the hydrologic conditions for each year in the study period**.** Streamflow, consumptive use, instream flows, diversions, irrigation returns, and reservoir conditions are the basic input data to the model. For all of this data, average values drawn from the dry, normal, or wet subsets of the study period were computed for use in the spreadsheets. The models do not explicitly account for water rights, appropriations, or compact allocations, nor is the model operated based on these legal constraints. It is assumed that the historical data reflect the effects of any limitations that may have been placed upon water users by water rights restrictions.

There are 12 spreadsheet workbooks, one for each of the normal, wet and dry hydrologic conditions for each of the four subbasins:

- Upper Green River Basin from the Green River headwaters to Flaming Gorge
- Blacks Fork River Basin from the Blacks Fork and Smiths Fork headwaters to Flaming Gorge
- Henrys Fork River Basin from the Henrys Fork headwaters to Flaming Gorge
- Little Snake River Basin from the Little Snake headwaters to the USGS stream gaging station on the Little Snake River near Lily, CO.

Model Structure and Components

Each of the Green River sub-basin models is a workbook consisting of numerous individual pages (worksheets). Each worksheet is a component of the model and completes a specific task required for execution of the model. There are five basic types of worksheets:

- **Navigation Worksheets:** are Graphical User Interfaces (GUIs) containing buttons used to move within the workbook.
- **Input Worksheets:** are raw data entry worksheets (USGS gage data or headwater inflow data, diversion data, etc.).
- **Computation Worksheets**: compute various components of the model (gains/losses).
- **Reach/Node Worksheets:** calculate the water budget node by node.
- **Results Worksheets**: tabulate and present the model output.

To mathematically represent each sub-basin system, the Basin river system was divided into reaches based primarily upon the location of major tributary confluences. Each reach was then sub-divided by identifying a series of individual nodes representing diversions, reservoirs, tributary confluences, gages, or other significant water resources features. The resulting network of reaches and nodes is a simplification of the real world which the model represents. Figures 7-1, 7-2, 7-3, and 7-4 are node and reach diagrams for each of the four subbasins: the Upper Green River Basin, Blacks Fork River Basin, Henrys Fork River Basin, and the Little Snake River Basin.

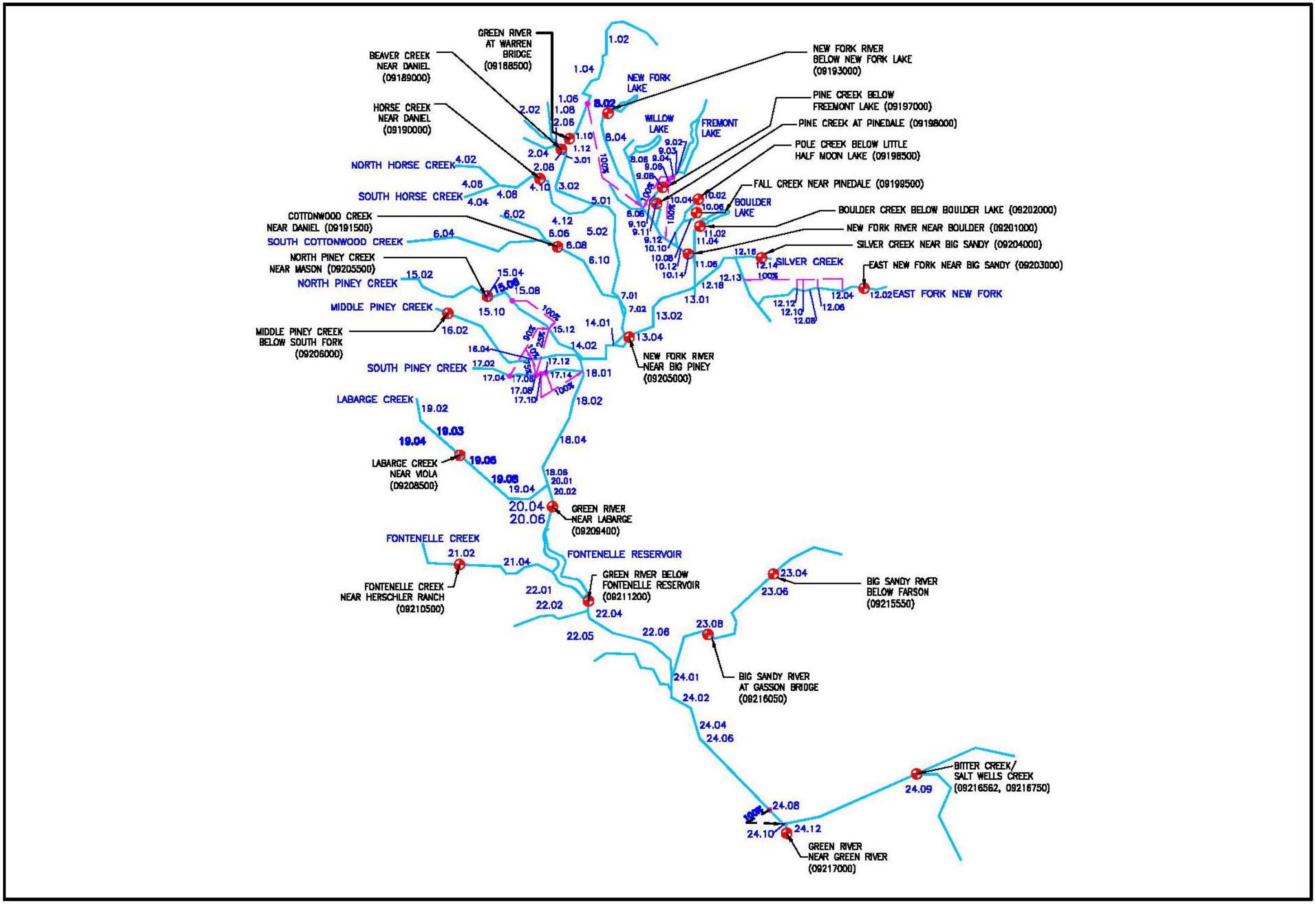


Figure 7-1
Green River Basin
Upper Green Node Diagram

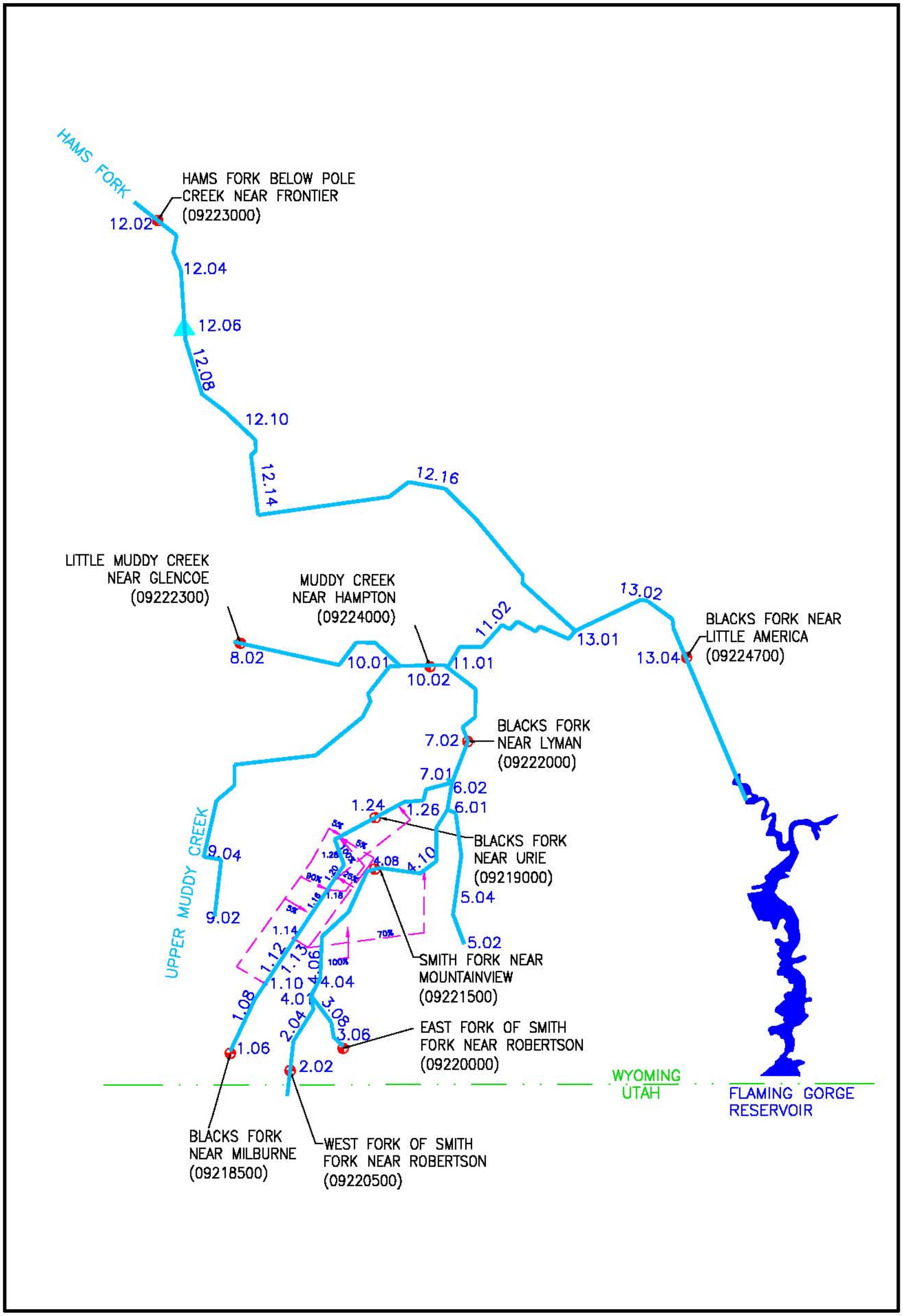


Figure 7-2
Green River Basin
Blacks Fork Node Diagram

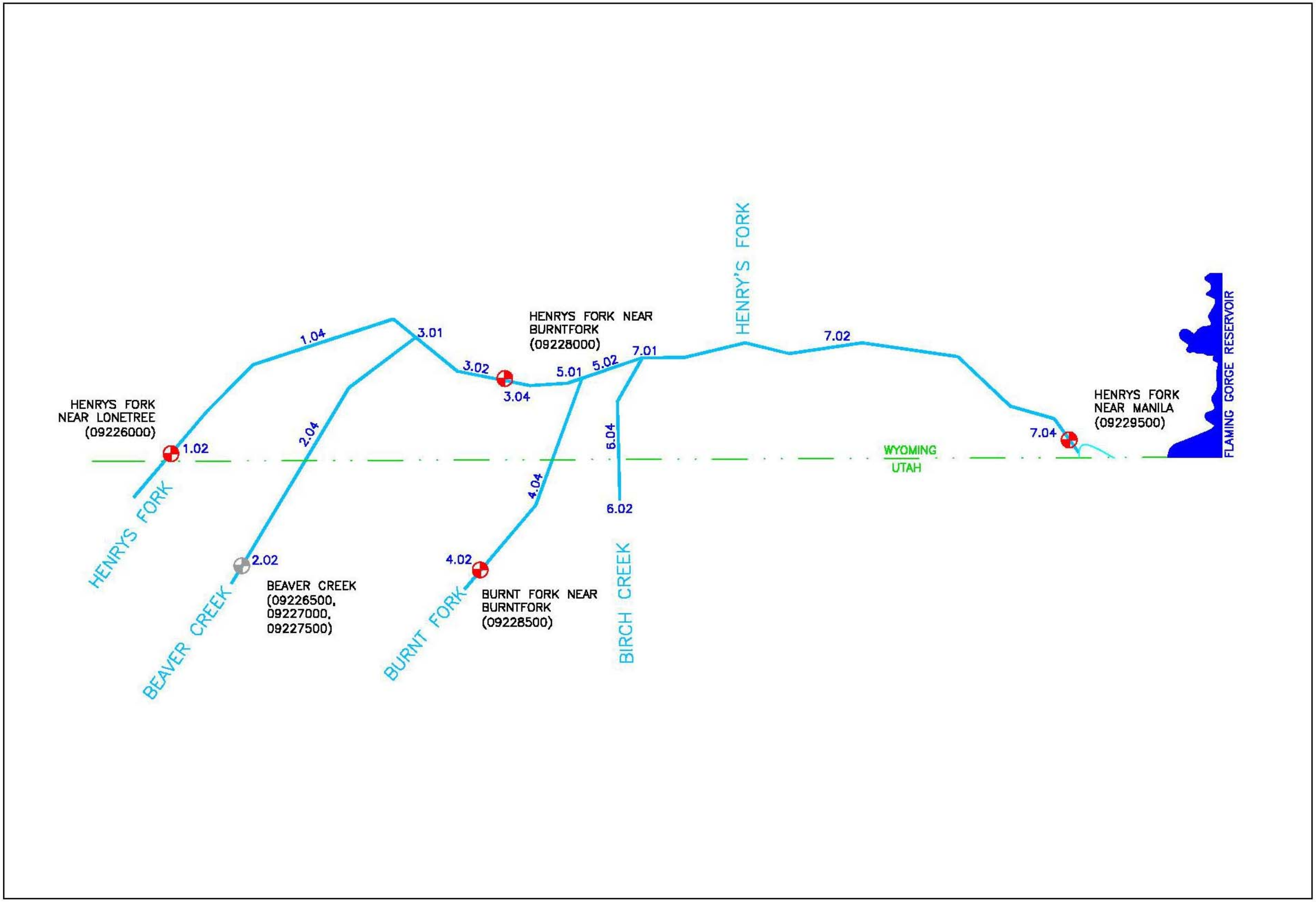


Figure 7-3
Green River Basin
Henrys Fork Node Diagram

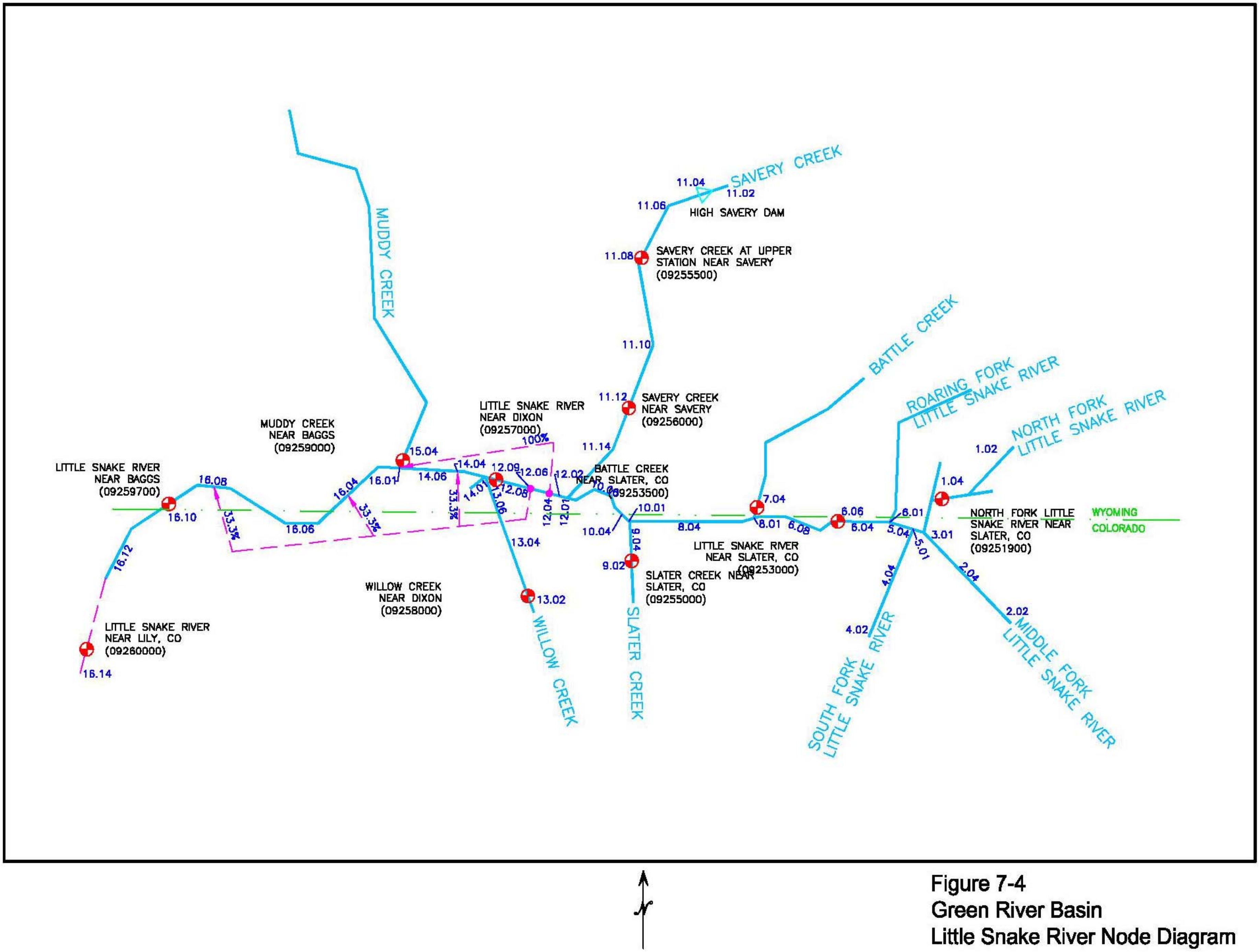


Figure 7-4
Green River Basin
Little Snake River Node Diagram

Stream Gage Data

Monthly stream gage data was obtained primarily from the USGS website and supplemented by the annual SEO hydrographers' reports or U.S. Bureau of Reclamation gage data for each of the stream gages used in the model. Linear regression techniques were used to estimate missing values for the gages that had incomplete records. Once the gages were filled in for the study period, monthly values for dry, normal, and wet conditions were averaged from the dry, normal, or wet years of the study period. The dry, normal, and wet years were determined on a subbasin level from indicator gages that covered the Basin, were relatively free of influence by human activities, and were reasonably complete during the study period. Headwater inflow at several ungaged locations is estimated. The estimated inflows are treated as if they were gaged flows by the model.

Diversion Data

Surface water diversions are made up of agricultural, industrial and municipal diversions. Agricultural use is by far the largest diverter for irrigation purposes. However, industrial and municipal uses also rely on surface water diversions. Agricultural diversions are more sensitive to hydrologic conditions due to the lack of supplemental storage and the model reflects changes in agricultural diversions due to wet, normal, and dry years. Municipal diversions are typically fairly constant despite hydrological conditions and thus were modeled using both depletion values shown in Chapter 5 and historical diversion records. Industrial depletions are also fairly constant and generally 100 percent consumptive. Industrial use values from Chapter 5 were used in the model.

Data on the diversion data sheet are used to calculate ungaged reach gains and losses, and in some cases, inflow at ungaged headwater nodes. They are also used as the diversion demand in the Reach/Node worksheets.

Reach Gain/Loss

The models simulate major diversions and features of the basins, but minor water features such as small tributaries lacking historical records and diversions for small permitted acreages are not explicitly included. Some features are aggregated and modeled, while the effects of many others are lumped together using a modeling construct called "ungaged reach gains and losses." These ungaged gains and losses account for all water in the water budget that is not explicitly named and can reflect ungaged tributaries, groundwater/surface water interactions, lagged return flows associated with structures that divert consumptive use only in the model, or any other process not explicitly or perfectly modeled.

The only imports or exports modeled in the Green River Basin Models are the Cheyenne Stage I and Stage II exports from the upper reaches of the North Fork of the

Little Snake River. Historical records were obtained for the study period and monthly exports were averaged for the dry, normal, and wet years.

7.1.4 Stream Flow Estimates

An output worksheet in each spreadsheet model that summarizes monthly flow is computed at each node to determine the amount of water that flows downstream out of the node and provides the basis of this availability analysis. In general, simulated flow at each node terminus indicates how much water is physically present, but it may not fully reflect flow that is available for future appropriation. This apparently "available flow" may already be appropriated to a downstream user, may be allocated downstream to satisfy compact or decree obligations, may be satisfying an instream flow right, or may result from reservoir storage water being delivered to specific points of diversion downstream. It is important to acknowledge these existing demands when determining developable flow, as distinguished from physically available flow.

To determine how much of the physical supply is actually developable for future uses, physical supply at a node terminus must be reduced to provide for the following circumstances:

- assumed approval of pending instream flow right applications.
- deliveries of storage water.
- Total values must exceed the remaining developable allowance as limited by the Colorado River Compact and Upper Colorado River Basin Compact to have available water.

The flow that is physically present and could be developed for future uses at each point is defined as the minimum of the physical supply value, adjusted to take into account instream flow demands and the adjusted physically present flow at all downstream reaches. In other words, if adjusted physical supply at the node is the limiting value, then all that water can be removed from the stream without impacting either instream demand at this location or downstream appropriators. Thus, water available for future appropriation must be defined first at the most downstream point, with upstream availability calculated in stream order. These calculations were made on a monthly basis with annual availability computed as the sum of monthly available water. Calculating annual availability in this way can yield a different value than applying the same logic to annual flows for each reach; the summation of monthly values is more accurate, reflecting constraints of downstream use on a monthly basis.

The reader should note that this physically available supply adjusted for downstream demands and delivery of storage water is further subject to the Upper Colorado River Basin Compact and the Colorado River Compact limitations.

As virgin flow estimates were not prepared in the Green River Basin, a comparison of present flows to current levels of depletion was made. Table 7-1 shows the flows that were estimated for the average or normal hydrologic condition for the current plan and the 2001 plan; these flow estimates were reduced by the current depletions estimated in Chapter 5. The reduction in streamflow leaving the state since 2001 can be attributed to increased consumptive use, a drier study period, refined availability analysis based on the more accurate node water analysis rather than reach water availability, the inclusion of five instream flow permits rather than just the one that existed in the study area in 2000, and the construction and incorporation of High Savery Reservoir into the spreadsheet.

Table 7-1 - Current Surface Water Availability Estimates Compared with 2001 Plan Estimates

	2001 GRBP	2010 GRBP	Difference	% Difference
	Acre-Feet / Year			
Blacks Fork				
Dry	101,000	67,000	-34,000	-34%
Normal	299,000	195,000	-34,000	-15%
Wet	422,000	398,000	-24,000	-6%
Henrys Fork				
Dry	23,000	24,000	1,000	4%
Normal	60,000	52,000	-8,000	-13%
Wet	125,000	118,000	-7,000	-6%
Little Snake				
Dry	189,000	177,000	-12,000	-6%
Normal	449,000	407,000	-42,000	-9%
Wet	665,000	642,000	-23,000	-3%
Upper Green				
Dry	620,000	595,000	-25,000	-4%
Normal	1,269,000	1,138,000	-131,000	-10%
Wet	1,924,000	1,806,000	-118,000	-6%

StateMod Model

As part of this 2010 Green River Basin Plan, StateMod, a general water allocation model, was extended to match the area covered by the spreadsheet model for comparison of the results of the two models and calibration of StateMod. StateMod is a model used to distribute the natural water supply to users according to their demand and the prior appropriation doctrine throughout a specified modeling period. StateMod is fundamentally different from the spreadsheet models in that it steps through each month of the study period, whereas the spreadsheet models reflect three different years that typify normal, wet, and dry conditions. The StateMod model dynamically “decides” where water can be diverted based on characteristics of the diversion or reservoir structures and water rights, whereas the spreadsheet models strictly reflect historical water uses and operations. Underlying hydrologic data is the same for the two models, but the extremes of record are played out in StateMod representation of specific years such as 1977 or 1986, while the spreadsheet model averages the driest and wettest years in with the rest of the lowest/highest 20 percent of years to produce a less extreme hydrology. Lastly, the spreadsheet models depend on irrigation water requirements developed at the University of Wyoming, for the period 1965 through 1990, while the StateMod model uses the modified Blaney-Criddle method in each irrigation season time step, incorporating crop coeffieients that were calibrated to the University of Wyoming datasets. The results of the StateMod model as compared to the spreadsheet model are presented in Table 7-3.

7.1.5 Basin Supply Estimates

The amount of physically available water is depicted in Table 7-2 and Figure 7-5 as the available flow at specific points of the Green River Basin.

Table 4-1 shows the current amount of physically available water less current depletions for the normal, dry and wet hydrologic conditions. This table shows that the Green River Basin has adequate surface water resources to meet its diversion requirements and satisfy the Colorado River and Upper Colorado River Basin Compacts for normal, wet, and dry hydrologic conditions. It is important to note that these margins of available water are smaller than estimated in the 2001 Green River Basin Plan. This change is caused by the difference in annual water availability averages between the two basin plans; since 2001, two thirds of the intervening years have been dry and none have been wet, decreasing the average amount of estimated water availability. Consumptive use has also increased nominally further lessening the margin of available water.

StateMod Model

According to the StateMod model, average annual water availability at the USGS Green River gage is 1,211,000 acre-feet per year. This represents an average for years 1971 through 2006. However, if StateMod results for the normal, wet, and dry study years are averaged, the results can be compared with results from the spreadsheet models relatively well. Table 7-3 shows this comparison.

The greater estimate of flows in the historical diversions scenario is probably most related to spatial distribution of the baseflow gains. Baseflow can be estimated at the stream gages, which provide a "window" to the baseflow. Between these windows, the modeler must estimate where the gain from gage to gage accrues to the stream. If the estimate is incorrect, the modeled diverters may not have access to water that was available historically, and the diversion is shorted. To the extent that the diversion and associated consumption do not occur, extra water "shows up" somewhere downstream.

The crop-based demand scenario produced lower simulated flows at Green River than the historical diversions scenario (although not lower than gaged values for normal and wet years) because the estimated demand can be greater than the historical diversion in any given month, and if there happens to be water available, the simulated diversion will take the water. For example, May and September demand is based on a crop requirement that reflects temperature and precipitation. If a farmer chose not to divert in May because his headgate is still under snow, or in September because he has cut his hay, the model will still divert water at these times. Another source of discrepancy between historical diversion estimates and crop-based demand is related to the absence of information about first and last use of irrigation water for the season. These dates are not typically recorded. If the first diversion rate observation is actually made several weeks into the diversion season, then the estimate of historical diversions does not truly reflect demand. In this case, the crop-based estimate may be closer to reality.

Table 7-2 - Physically Available Flows in the Green River Basin

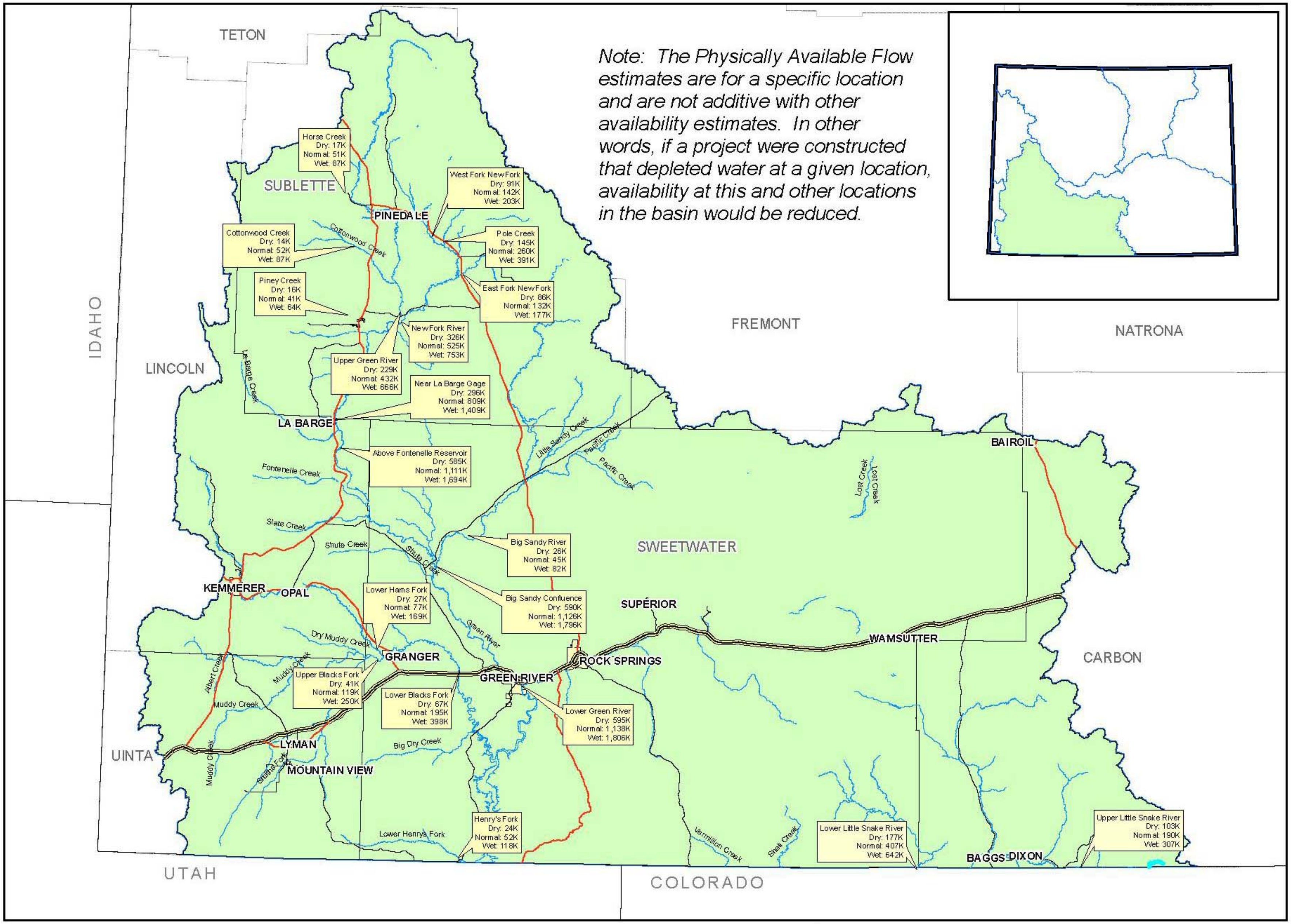
	Hydrologic Condition		
	Dry	Normal	Wet
Water Body	Acre-Feet/Year		
Henrys Fork	23,638	51,809	117,786
Lower Blacks Fork	66,736	195,082	397,706
Lower Hams Fork	27,275	76,696	169,218
Upper Blacks Fork	41,413	118,960	249,913
Upper Little Snake River	103,316	189,759	306,920
Lower Little Snake River	177,321	406,658	641,712
Lower Green River	595,320	1,137,732	1,806,305
Near LaBarge Gage	296,009	808,709	1,408,842
Above Fontenelle Reservoir	584,924	1,110,921	1,693,716
Upper Green River	229,097	432,010	666,489
Big Sandy River	25,813	45,291	82,412
Big Sandy Confluence	589,706	1,126,008	1,796,457
New Fork River	325,886	525,043	753,308
Horse Creek	17,021	51,054	87,034
Cottonwood Creek	13,852	51,659	86,976
West Fork New Fork	91,238	141,983	203,114
Pole Creek	144,863	259,658	391,295
East Fork New Fork	86,377	131,947	176,674
North Piney Creek (below Musselman)	15,904	40,665	63,966

Source: "Available Surface Water Determination," tech. memo, AECOM, 2010 (T)
Note: Estimates made using spreadsheet model as described in the above referenced technical memo.

Table 7-3 - Water Availability Estimates at the USGS Green River Gage using Spreadsheets and StateMod Models

	Dry	Normal	Wet
	Acre-Feet/Year		
Spreadsheet Result	595,000	1,138,000	1,806,000
StateMod Result (Historical Demand)	601,000	1,179,000	1,835,000
StateMod with Crop-based Demand Result	555,000	1,165,000	1,825,000

Source: “Available Surface Water Determination,” tech. memo, AECOM, 2010 (T)



LEGEND

Water Body Dry: 0K Normal: 50K Wet: 100K

Physically Available Flow, thousand ac-ft

N

Figure 7-5
Green River Basin Physically Available Flows

7.1.6 Future Supply Estimates

The most conservative estimate of water availability for the future is the dry hydrologic condition depleted by the projected use amounts discussed in Chapter 6. The most likely projection scenario for the Green River Basin is the moderate scenario, and those values are used to estimate future depletions here. Table 7-4 shows the flow estimates resulting from the moderate scenario depletions during dry hydrologic conditions. Based upon the estimates shown in Table 7-4, the Green River Basin will still have adequate water supplies under current estimates of Wyoming's compact allocation in the year 2055 to satisfy the Upper Colorado River Basin and Colorado River Compacts. The Green River Basin will have approximately 150,000 to 250,000 acre-feet of unused water under the compacts and assuming that water augmentation and conservation projects will most likely be more developed in the future, these may be underestimates of the amount of future available water.

7.2 GROUNDWATER

7.2.1 Background

The availability of groundwater is a function of the physical characteristics of the aquifer at the location of interest (see Chapter 4) and the value of the intended use. For example, an industrial user may be able to afford to drill deep wells, sustain large drawdowns, and treat groundwater of undesirable quality, whereas an irrigation use may be economical only where wells are shallow, production is high, and quality is adequate without treatment. Virtually any of the "major" aquifers described in Chapter 4 could provide useful groundwater supplies, given sufficient development value. The "minor" and "marginal" aquifers could provide modest supplies of good-quality groundwater at many locations. Successful groundwater development in the "major aquicludes" group will be dependent upon locally favorable conditions and minimal quantity and quality demands.

Development of groundwater in sufficient quantities and of sufficient quality to meet specific project goals will require site-specific hydrogeologic analyses. None of the aquifers discussed in Chapter 4 are universally productive and none are entirely free of water quality concerns. While the generalizations of this report can provide guidance on the location and potential of various aquifers, local evaluation programs are essential to development success.

Table 7- 4 Future Average Annual Streamflow - Dry Hydrology and 50 Year Moderate Growth Scenario.

Surface Water Depletion Estimate in 2055 Moderate Growth Scenario	Acre-Feet/year
Municipal	11,596
City of Cheyenne	22,700
Industrial	123,700
Agricultural	399,480
Evaporation (In-state)	32,800
Recreation	NC
Environmental	17,000
Depletions Sub-Total	607,276
Full Development Main Stem Evaporation Charge	72,800

A.)	Total Depletions	680,076
B.)	Dry Scenario Total Streamflow from Table 4-1	1,452,316
C.)	Flow Leaving Wyoming, 2055 Growth, Dry Scenario (B-A)	772,240
D.)	Remaining Compact Amount, assuming 847,000 ac-ft allocation	166,924

Notes

Environmental Surface water depletions are those due to man made reservoirs used for environmental purposes.

NC = Non consumptive

2010 Basin Plan Estimate of Ag Surface Water Use is from Table 6-1. Derived by assuming equal to the irrigation consumptive use minus 7,800 ac feet for groundwater use in irrigation plus 1/2 projected stockwater uses. This assumes that Stock use is 50% surface and 50% groundwater.

2010 Basin Plan Estimate of Municipal Surface water use from Table 6-3

2010 Basin Plan Estimate of Cheyenne Surface water use from Table 6-5

2010 Basin Plan Estimate of Industrial surface water use from Table 6-10

2010 Basin Plan Estimate of Environmental Use from 2001 Plan, 30yr

Compact Allocation Estimate per SEO, October 1, 2010.

The State can store 120,000 ac-ft of water in Fontenelle Reservoir. The estimate of Remaining Compact Amount (Item D) is based on the assumption that the future industrial depletion shown will be met, at least in part, by the State of Wyoming Fontenelle Water Storage account.

The relationship between the groundwater and surface water portions of the overall water resource depends upon the location, depth, rate, volume, and use of the groundwater withdrawn, all in the context of the local and regional hydrogeologic environment. When a well is pumped, groundwater is removed from storage, creating a cone of depression. That cone will grow deeper and broader as pumping continues until a balance is established between pumping from the aquifer and inflow to the aquifer from 1) adjacent water-bearing rocks and/or 2) surface water sources. The latter may include stream infiltration induced by pumping, interception of groundwater flow that would otherwise continue towards discharge at the surface, or production of groundwater that would otherwise be taken up and transpired by plants (a capture process known as "ET salvage").

7.2.2 Diversion Rates

In general, groundwater diversion rates of less than 5 gallons per minute (gpm) are widely, although not universally, available throughout the Green River Basin. Diversion rates in the 5 to 50 gallons per minute (gpm) range are likely obtainable from most of the "major aquifers" shown on Figure 4-3. In the Green River Basin, 95.2 percent of groundwater wells have permitted yields of 25 gpm or less. Diversion rates in excess of 50 gpm may require favorable local conditions of permeability. Rates on the order of 1,000 gpm are only routinely available from certain areas of productive alluvium and from well-recharged and fractured areas of major bedrock limestone aquifers. There are 203 wells in the Green River Basin with yields from 100 to 3,600 gpm, and of these only 19 are in the 500-3,600 gpm range. Figure 7-6 presents data on groundwater wells in the Green River Basin. The above assessments are based upon instantaneous diversion rates that may or may not represent the conditions necessary to sustain those rates over extended periods when subject to the cumulative impacts of multiple wells or when stream depletion is an issue.

In addition to diversions, aquifer discharge of the main Tertiary Aquifer System in the Green River Basin is estimated to be 118,000 acre-feet/year, as shown in Table 7-5, and should be considered a constant diversion of groundwater.

7.2.3 Groundwater in Storage

A large quantity of groundwater is stored within the aquifers of the Green River Basin, although this quantity is very difficult to estimate accurately. The depth to the groundwater table is rarely more than a few hundred feet and beneath that water is stored in the pore space of the rocks to a depth where porosity falls effectively to zero, e.g., in the crystalline rocks known as "basement." Green River Basin Mesozoic sedimentary rocks—sandstone, shale, limestone, conglomerate—extend to depths of 30,000 feet. Thus there is a vast amount of groundwater in storage, although much of it is too expensive to develop as a useful resource due to unfavorable permeability, depth, or quality. Because

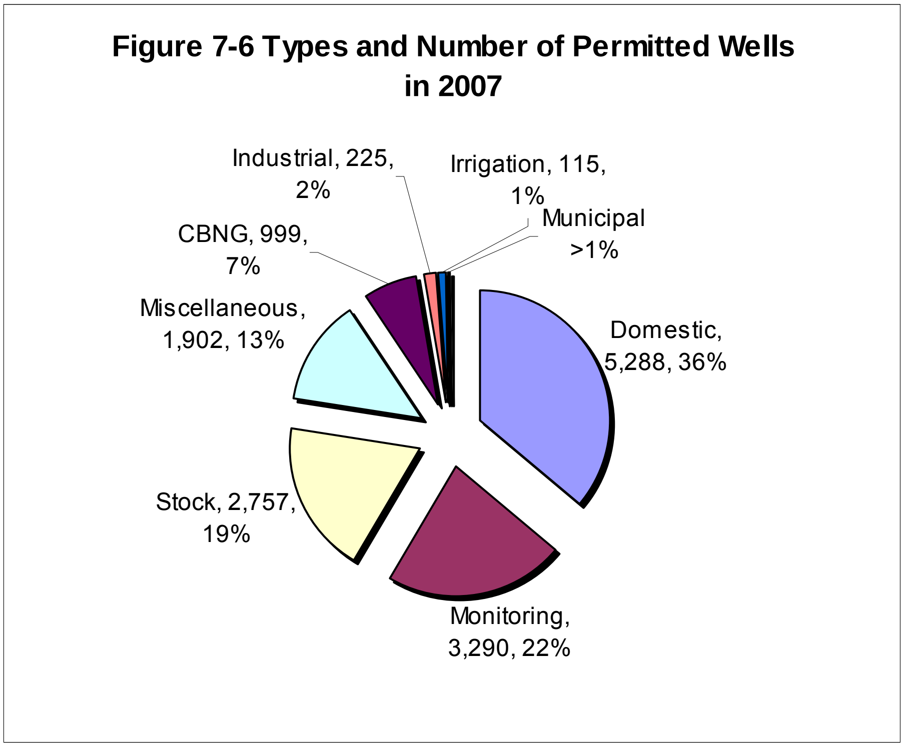


Table 7-5 - Estimated Discharge of the Tertiary Aquifer System

Discharge Component	Estimated Outflow Cubic-Feet/Second
Green and New Fork Rivers upstream from Fontenelle Reservoir	94
Green River between Fontenelle Reservoir & Green River, WY	23
Green River downstream from Green River, WY, including Flaming Gorge Reservoir	13
Big Sandy River	17
Henry's Fork River	16
Total	163
Total in Acre-Feet/Year	118,000

Source: Available Groundwater Determination, tech. memo, 2010 much of the groundwater is stored at these infeasible depths, calculations of groundwater in storage were conducted on the most heavily used and accessible Tertiary Aquifer system in the Green River Basin.

The Wyoming State Geological Survey (WSGS) carried out general calculations on rock and sand volumes in the top 1,000 feet of good quality water bearing portion of the Tertiary Aquifer in the Green River Basin to get a rough estimate of the amount of groundwater in storage. These calculations took into account estimated porosities of each substance, surface area covered by the aquifer, the vertical saturated thickness of the aquifer, and assumed the composition of the aquifer to be sandstone topped with unconsolidated sand. The total estimated quantity of groundwater contained in the Tertiary Aquifer system is approximately 1 to 2 billion acre-feet of water. However, this number does not represent the total quantity of groundwater that may be yielded to wells due to hydrostatic forces of water in the ground. Complete explanations of this estimate are contained in the *Available Groundwater Determination, tech. memo, 2010* referenced at the end of this chapter.

Groundwater in storage can be viewed as 1) a surface reservoir, from which water can be extracted repeatedly as it is subsequently refilled, or 2) a groundwater "mine", from which water can be extracted one time. The alluvial aquifer is most akin to a surface reservoir. It is filled either by stream flow infiltration or groundwater recharge that would otherwise proceed into the stream. Removal of stored water from an aquifer reduces stream flow, and that reduction continues until the reservoir is refilled. Where quantities of water in excess of contemporaneous stream flow are needed seasonally, the groundwater reservoir can be exercised to better align demands with supply by "evening out" surpluses and deficits. This process happens naturally across many of Wyoming's irrigated lands, as large springtime diversions generate return flows that sustain late-season stream flows.

While groundwater will ultimately be replaced from surface sources, that replacement may be so diffuse and over such a long time period that it is effectively a nonrenewable resource. In general, the deeper and more distant from surface water features the groundwater is, the smaller is the likelihood of a significant surface water connection.

The removal of groundwater from storage is indicated by a lowering of the groundwater table or in the case of a confined aquifer, by a decrease in pressure. Bedrock aquifers are generally deeper and more distant from streams than are alluvial aquifers and are more likely to experience groundwater level declines before production rates and recharge rates come into balance. Short-term fluctuations in groundwater levels may reflect seasonal variations in recharge and discharge, multi-season climate cycles, or deliberate drafting and recovery management. Long-term changes in groundwater levels indicate a deficit (or, in some cases, a surplus) of recharge relative to production. Where groundwater is closely connected with surface water, as in much of the alluvial aquifers, the locations and long-term availability of groundwater are effectively the same as surface water. Groundwater recharge is the source of "base flow" to streams. While matching groundwater consumption to recharge would prevent widespread groundwater level declines, it would also lead to dry streambeds for much of the year. Thus care must be exercised when extracting shallow groundwater resources in connection with surface water.

Except for some localized areas in the Green River Basin with a high density of existing wells, most of the remaining Basin area offers opportunities to develop additional groundwater resources. No areas have been identified in the Green River Basin with significant depletion (or “mining”) of the groundwater resources, which may require the establishment of a groundwater control area such as the groundwater control areas that currently exist within the Platte River Basin of southeast Wyoming. Two areas have recently started experiencing or are planning drawdown of water levels as a result of energy development. These two aquifers are the Tensleep Sandstone in the northeastern Great Divide Basin due to petroleum field development and the coal beds of the Mesaverde Group near Baggs due to the Atlantic Rim CBNG development. In addition, some degree of observed decline in the groundwater levels occurred across Wyoming, including the Green River Basin and adjacent areas, during the 8-year regional drought period from 1999-2007.

7.2.4 Groundwater Recharge

A common approach to estimating the quantity of groundwater available for continuous development, as opposed to one-time extraction, is to estimate groundwater recharge. Precipitation is the ultimate source for groundwater resources as part of the hydrologic cycle although man-made recharge may occur in local areas where human activities provide more water to the ground surface than occurs naturally. Examples of this include irrigation on cropland, reservoirs, irrigation canals and ditches, and industrial, stock, and wastewater ponds which all locally increase the infiltration quantity of water compared to the natural rate of precipitation.

It is generally assumed in hydrogeology that 10 percent of the amount of precipitation falling on the outcrops of bedrock formations infiltrates and recharges the aquifer. The average annual precipitation in the Green River Basin ranges from 6 to 59 inches per year with most of the Basin receiving 6 to 15 inches average annually. However, not all precipitation infiltrates into the ground to recharge the aquifer; a portion is consumed by evapotranspiration (the combined evaporation and transpiration losses of water in the vapor state to the atmosphere), overland flow, and runoff. Additionally, there are wet, average, and dry years with varying amounts of precipitation resulting in a range of possible recharge amounts depending on the hydrologic conditions of the year. Estimates of aquifer recharge rates range from less than one inch per year to twelve inches per year; generally the mountainous and highland areas experience greater recharge. Evapotranspiration rates in the Green River Basin are high because of the high altitude and arid climate. In the central basin areas the annual evapotranspiration rates exceed the annual precipitation rates to the effect that very little to no aquifer recharge occurs.

There is little consensus on a detailed estimation of groundwater recharge rates, which are a complex function of the seasonal timing, duration, intensity, and type of precipitation; the infiltration characteristics of the soil; the hydraulic properties of the uppermost geologic materials; and the manner in which groundwater recharge moves within and between aquifers. Previous estimates of groundwater recharge rates in the Tertiary Aquifer System of Green River Basin set the range of 50,000 to 100,000 acre-feet per year. Newer estimates in the *Available Groundwater Determination, tech. memo, 2010* approximate the number at about 119,000 acre-feet per year, as is shown in Table 7-6.

In summary, the above approach to estimating the amount of groundwater in storage and the total recharge to groundwater provide upper bounds on the possible supplies of mineable groundwater and sustainable groundwater production, respectively. As a practical matter, however, the available groundwater supply is substantially less.

7.2.5 Groundwater Quality

Most water uses have some sensitivity to water quality. Because of this, groundwater availability will be a function of how the quality from a particular aquifer and location aligns with the needs of a particular use. As explained in Chapter 4, natural groundwater quality is generally best closest to outcrop areas and deteriorates the longer groundwater has been in contact with aquifer minerals. This effect is weakest in the "major aquifers" and strongest in the "minor" and "marginal" aquifers.

Figure 4-5 shows an aquifer sensitivity map of the Green River Basin. These higher sensitivity areas are considered to be more susceptible to shallow groundwater contamination due to the increased permeability of these geologic units and also the relatively shallow depth to groundwater in these areas.

In some areas of the Green River Basin, groundwater contamination is natural and related to the elevated concentrations of chemical constituents from natural sources. Unnatural sources of pollution consist of mostly local incidences of spills and leaks. A more detailed commentary on groundwater quality is presented in Chapter 4.

7.2.6 Groundwater Summary

Groundwater availability is greatest for the Tertiary Aquifers in the Green River Basin, with the understanding that connections with surface water will have to be addressed. Table 7-7 shows SEO groundwater permits by type of use for the Green River Basin.

Table 7-6 - Estimated Recharge to the Tertiary Aquifer System

Recharge Component	Estimated Inflow Cubic-Feet/Second
Infiltration of precipitation, snowmelt runoff, and streamflow	138
Excess irrigation water in the Farson-Eden area	18
Streamflow leakage along the Blacks Fork, Smiths Fork, & Hams Fork Rivers	9
Total	165
Total in Acre-Feet/Year	119,000

Source: Available Groundwater Determination, tech. memo, 2010

Table 7-7 - 2007 Permitted Wells in the Green River Basin

Well Type	Number of Wells	Percentage of Total Wells
Domestic	5,288	36%
Monitoring	3,290	22%
Stock	2,757	19%
Miscellaneous	1,902	13%
Coalbed Methane (or CBNG)	999	7%
Industrial	225	2%
Irrigation	115	1%
Muncipal	55	>1%
Total	14,631	100%

Source: Available Groundwater Determination, tech. memo, 2010

7.3 WATER CONSERVATION

7.3.1 Introduction

In general, the Green River Basin has adequate water to serve the needs of its residents now and in the near future. For the most part water shortages are seasonal although their effects can be magnified by drought conditions. Water conservation is any beneficial reduction in water losses, waste, or use.

Sound long-range water conservation and planning measures and goals set forth by The Irrigation Association, an international organization founded in 1949, include:

- Measure all water use.
- Price water so as to recognize its finite nature, provide financial incentives to users who conserve water, and provide financial penalties to users who waste water.
- Hold all water users responsible for protecting the quality of the water that they use.
- Create financial systems to reward users of efficient irrigation systems.
- Create national education programs regarding the “absolute necessity of supporting regulatory policies which reward conservation and efficient water use”.
- Support water reclamation and reuse initiatives, particularly for irrigation, but also for municipal, industrial, and other water use sectors.
- Increase support for developing new water sources, including new conveyance and storage systems and incorporating into development plans appropriate environmental concerns.
- Maintain water conservation planning as an ongoing program.
- Promote policies which allow for the lease, sale, or transfer of “established water rights” and/or the lease, sale, and transfer of water without jeopardizing established water rights, whenever possible.

In recent years, dry conditions and record low storage levels in Lakes Mead and Powell have generated concern as to how to accomplish water curtailments when there is no plan in place to administer such a call which historically has never been necessary. The meaning of “curtailment” is complex and has specific definition under Article IV of the Upper Colorado River Basin Compact. It is beyond the scope of this document to explain the definition of curtailment and the reader is referred to the Compact document for the definition. Table 7-8 illustrates the impact of the recent drought period on the amount of water in Lakes Mead and Powell.

Table 7-8 - Upper Colorado River Basin Inflow and Principal Reservoir Storage

Water Year	Unregulated inflow into Lake Powell % of Average	Combined Lake Powell & Mead Storage in maf[1]	Lake Powell & Mead Storage as % of Capacity
1999	109	47.59	95%
2000	62	43.38	86%
2001	59	39.01	78%
2002	25	31.56	63%
2003	52	27.73	55%
2004	49	23.11	46%
2005	104	27.24	54%
2006	72	25.80	51%
2007	68	24.43	49%
2008	107	27.04	54%

[1]Million acre-feet.

Source: Wyoming State Engineer's Office. *2008 Annual Report*, 2008

Water conservation in Wyoming involves all uses including agriculture, municipal and domestic, industry, recreation, and environmental concerns. In the past, water conservation efforts were mainly focused on improving the efficiency of agricultural water use. Today, water conservation takes a multi-sector approach as conservation has different meanings at different times of the year and to different water users. The following is a discussion of water conservation activities and opportunities.

7.3.2 Agricultural Water Conservation

The largest water savings by quantity are generally realized by conservation in the agricultural sector, as it represents the largest use of water in the state. For this reason, much of the focus of water conservation is on irrigation practices.

Water is typically diverted from the river or stream into a canal or ditch, which is generally of earth construction and unlined. A significant portion of water diverted for irrigation can be lost during conveyance to the field through seepage, deep percolation, phreatophytes, evaporation, and so forth. The soils of the Green River Basin are predominantly porous; water will quickly percolate through these granular soils. Losses of 10 percent in irrigation ditches and canals are considered typical and normal; any ditches with a loss rate greater than 10 percent are candidates for rehabilitation. In the Green River Basin, there are a large number of ditches that exceed a 20 percent loss. Membrane liners have been used with good results on some of the large USBR canals around the state. Research has indicated that application of polyacrylamide (PAM) to the canal bottom and sides will reduce seepage losses and increase transmission efficiencies. Concrete, PVC incorporation, and fabrics are other more common and equally effective means of reducing seepage to surrounding soils. Where economics permit, replacing open ditches with pipelines can virtually eliminate conveyance losses.

Irrigation methods also present an opportunity for water conservation. Historically flood irrigation was the most popular method used and still is very popular despite its low efficiency. The use of gated pipe and surge valves has somewhat improved the efficiency of flood irrigation practices by reduction of runoff, seepage in laterals and deep percolation, but overall effectiveness remains low. Since the early 1970s many areas in Wyoming have converted to sprinkler irrigation, including hand lines, wheel lines, big guns, and center pivot systems. Sprinkler design and efficiency have also increased over time with the use of low energy consuming or low pressure application systems. Positive results from this transition to sprinkler irrigation include increased crop yields and allowing more acreage to be irrigated in the late season. Negative effects include less groundwater recharge and decreased enhanced late season streamflow due to reduced irrigation return flows.

Irrigation districts typically have very limited resources to expend on canal lining and covering efforts. A change in some areas to less water-intensive crops or, to a lesser extent, landscaping, would potentially reap savings in water consumption. Moving from flood irrigation to sprinkler methods, as well as enclosure and lining of open ditches and canals would further conserve water. Changing to less water-intensive crops and landscaping should most likely be held in reserve, since it has a high impact on accustomed ways of farming and life.

7.3.3 Municipal and Domestic Water Conservation

The Green River Basin municipal water suppliers are faced with several problems. They must provide sufficient water of good quality and plan for the demands of potential future growth. Some of the municipalities are experiencing additional growth through economic development efforts while others are dealing with impacts from energy exploration and development. The water suppliers also must comply with state and federal water quality standards, which are constantly revised and becoming more stringent; compliance is becoming more and more costly. Typically, the budgets for water system improvements, operation and maintenance are based on revenues from the sale of water; many municipalities must sell water to meet their financial obligations.

Conservation measures generally consist of individual customer meters that track actual water use, and can help determine if there are major losses in the distribution system through leaks. Many municipalities meter their public water systems, but some systems do not and have little or no incentive to conserve water. The expense of installing meters can be seen as prohibitive and is unpopular politically. Some systems are requiring meters on new hookups and considering phasing in metering for the existing population. Leak detection and repair in municipal systems, reclamation and recycling, and residential plumbing improvements are all proposed water conservation possibilities in the municipal and domestic domain of water use. Conversely, some systems encourage water use during the winter months to prevent frozen pipes.

Reclamation and recycling efforts have not so far been emphasized in the Basin given the high cost of water treatment systems and the ready availability of water. The use of partially treated wastewater for irrigation of golf courses and public green spaces has been implemented in some areas and could be considered on a case by case basis. A study for the town of Rawlins showed that the treatment plant output water was too brackish to be used for long-term irrigation without further treatment, and the towns in the Green River Basin would have a similar problem given the similar characteristics of the water and soils of the region to Rawlins.

Within the identified opportunities, small municipalities within the Basin may have difficulty with certain improvements from a cost/benefit perspective; however, all the conservation options are valuable from a publicity and educational standpoint. Particularly costly for the municipalities are the infrastructure repair efforts, for which bonds and financing can be a hard sell to the local populations unless water shortages are imminent.

7.3.4 Industrial Water Conservation

Industrial water use is important as industry employs a significant percent of the Basin’s work force and constitutes a large portion of the Green River Basin’s economy. Conservation by industry is constrained by cost-benefit ratios; the necessity of making a profit will outweigh water conservation measures. Thus conservation by industry differs by industrial sector.

Power plant modification can reduce consumptive use. The two large power plants in the Green River Basin, (Bridger and Naughton) both use an evaporative cooling mechanism with a combined annual consumptive use estimated in the Seven States Report at 33,230 acre-feet per year. The Seven States Report further suggests that most of this consumptive use could be eliminated if the plants were to retrofit to an air-cooled system. The costs of such a modification ($1,000 to $4,000 per acre-foot recovered) do not look promising at the present time, and there are cost penalties in the form of lower plant efficiency, but the opportunity certainly does exist.

Desalinization of brackish water, especially Wyoming CBNG production water, could augment the usability of waste water. At present, most CBNG water in the Basin is injected into deeper aquifers to avoid disposal and treatment costs and problems since the water is generally brackish. Assuming the cost of desalinization would be similar to that reported by the desalinization project in Yuma, Arizona, a base cost of about $700 to $2,000 per acre-foot would be expected, depending largely on the cost of electricity. In addition, there are water conveyance and collection problems because the CBNG wells are dispersed throughout the Basin. Currently, some ideas for this option are under study, but any solution based on this option would likely be applied first in the Powder River Basin.

7.3.5 Recreational and Environmental Water Conservation

Three federal programs, the Conservation Reserve Program (CRP), the Wetlands Reserve Program (WRP), and the Wildlife Habitat Incentives Program (WHIP) encourage the development of wildlife habitat on private lands. The CRP is administered by the Farm Service Agency of the U.S. Department of Agriculture (USDA) and provides incentive payments for various conservation practices that will enhance wildlife habitat, as well as improve water quality and reduce erosion. The WRP is administered by the Natural Resources Conservation Service (NRCS) of the USDA. It is a voluntary program that provides financial and technical assistance to private landowners to reestablish wetlands on their property. The WHIP is also administered by the NRCS, and it provides technical and financial assistance to private landowners interested in improving wildlife habitat on their property. None of these programs result in significant amounts of consumptive water use. More lands in the Basin are expected to be enrolled in the CRP in the future, although no acreage estimates were made for purposes of this water plan. Most CRP lands do not involve consumptive use of surface water and thus will not affect future surface water availability for other uses.

Funding for non-consumptive uses such as environmental and recreational uses is a concern. There also exists the notion that environmental and recreational needs are not always compatible with storage. Where instream flows are desirable, the hydrology of the natural stream system still cannot put water into the river in a dry year unless those flows are tied to storage. Compounding the conflict, where run-of-the-river hydrology is favorable for aquatic and riparian habitats (and recreation pursuits), the reservation of flows for this purpose, while valuable, may preclude the use of this water for other consumptive needs allowed under the governing compacts. In fact, Wyoming's Instream Flow Law requires that instream flow use "shall not result in more water leaving the state than the amount of water that is allocated by interstate compact or United States Supreme Court Decree for downstream uses outside of Wyoming."

7.3.6 Conclusion

In order for conservation methods to be successfully implemented, there must be an incentive or benefit for those involved. This incentive may be in various forms, such as increased crop yields, improved fishing, reduced costs, and so forth.

Reduction of conveyance losses and improvement of irrigation efficiency do not necessarily equate to less water used. In areas of deficit, conservation measures may result in the conserved water being applied to additional acres or providing a full supply of water throughout the season without a decrease in the water diverted. However, these improvements in efficiency will likely result in an increase in the crop quality and yield.

Under the prior appropriation doctrine, water left in the stream is available to other users. An appropriator can invest in conservation measures that result in the water savings remaining in the stream, however, there is presently no mechanism whereby the appropriator can capitalize on those savings and realize an economic gain for his investment. As a result there is little incentive to invest in conservation measures that leave water in the stream for use by others.

The Green River Basin has surplus water when viewed from a basinwide perspective. Because there is excess water supply, local motivation to support intensive or even modest investments of time and money on water conservation is not strong. The state should promote conservation as a best practice policy, consider changing water law to reward conservation efforts to the appropriate stakeholders, support all local efforts and initiatives toward water conservation, particularly as irrigation districts consider conveyance improvements which may be beyond their means but of benefit to the Basin as a whole, and continue to monitor the conservation studies and efforts of others, particularly the Lower Colorado Basin work. Since the Green River Basin's situation is unique and dynamic, the opportunities and economies for conservation may differ from those found in other locations, but water users in the Basin should continue to evaluate and develop conservation as one important piece of the water resource puzzle.

7.4 REFERENCES

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